

Select a hearing protector with uniform response attenuation

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The importance of protecting one's hearing is widely known. Despite this, how many people protect their hearing during a concert? Just look around you: 3%, 5%? A significant amount of awareness must be created, and not just among youth.

Attending a concert, communicating...with traditional hearing protectors available today, this has become a challenge. Distortion resulting from classic attenuation hinders the proper perception of sound. The uniform response hearing protector is THE solution that will enable faithful perception of sound while ensuring protection.

A hearing protector with uniform response will provide identical attenuation on each frequency band. This uniformity will allow a faithful reproduction of sound by reducing the sound level.

Many products claim to meet the requirements of users seeking "natural" hearing protection.

While some manufacturers take advantage of the ignorance of their customers and offer them products that are no more uniform than simple foam earplugs, many products allow sound quality that is quite good and very close to the original, limiting the risk of hearing loss.

The objective of this study is to give you pointers to select the the most suitable hearing protector according to your means, noise exposure, and its duration.

Protection against noise
E-118.3



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1 Noise

In France, two out of three people are affected by noise. Anxiety, stress, irritability, fatigue, decreased concentration, and sleep disturbances are among the many effects of noise on the body; hearing loss is the main risk.

Irreversible effects on hearing due to excessive noise exposure can include tinnitus (permanent ringing or buzzing), acoustic trauma (loud noise), or permanent hearing loss, which is typical of a prolonged exposure to very high sound intensities.

1.1 Noise dose

A risk of hearing loss exists from exposure to 80 dB (A) for eight hours a day (DIRECTIVE "NOISE" 2003/10 / EC OF THE EUROPEAN PARLIAMENT, 2003). The higher the noise level, the higher the exposure time from which a risk is reduced. An employee working on a machine and exposed to 86 dB (A) endangers his hearing if left exposed for more than two hours a day. A spectator at a rock concert near the loudspeakers that broadcast an average sound level of 110 dB (A) will be in danger if he stays there for more than twenty seconds without hearing protection.

With each doubling of the sound source, the level increases by 3 dB (logarithmic change). The duration of exposure should be halved to avoid risks given in Table 1.

Sound Level dB(A)	Maximum duration of exposure in hours
80	08:00:00
83	04:00:00
86	02:00:00
89	01:00:00
92	00:30:00
95	00:15:00
98	00:07:30
101	00:03:45
104	00:01:22
107	00:00:41
110	00:00:20

Table 1: Correspondence between the noise level and the maximum exposure (in the absence of any other noise exposure)

The noise dose is the conjunction of two factors, time of exposure to noise and noise levels during this exposure.

1.2 Type of noise

The noises have different natures; they may be acute, severe. They are recognizable by their signature sound. It is very easy to tell the difference between the sound of a drill and that of a motorcycle, between the barking of a dog and the meowing of a cat; it is also easy to recognize the voice of a child, a man, a woman, a loved one, etc.

Our ear is stimulated almost constantly, consciously and unconsciously, by the sounds that surround us.

Every sound is composed of vibration frequencies that make its signature.

Each frequency is important. People with hearing loss at high frequencies, for example, encounter many difficulties in communication when they are in a noisy environment. They miss a part of the code, and comprehension becomes a tiring and permanent decoding task, leading gradually to isolation.

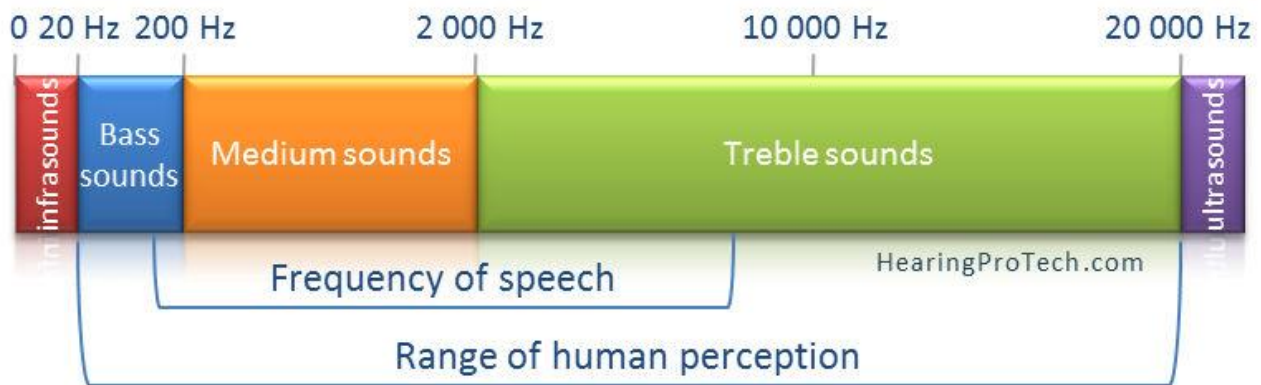


Figure 1: Human perception zone (20 Hz to 20 kHz) and zone of frequencies emitted by the voice (50 Hz to 8 kHz).

1.2.1 Human perception

As we age, we experience a progressive hearing loss called presbycusis that especially affects our perception at high frequencies. At the age where an ear is perfectly developed (0 to 30 years), the maximum audible frequency is unpredictable. Some people do not perceive anything beyond 8000 Hz, while others hear up to 24,000 Hz. It is the same for low frequencies, the variability from one individual to the other ranges from 10 Hz to 30 Hz.

1.2.2 Frequencies of speech

All voice frequencies range from about 50 Hz to 8 kHz. Male and female voices differ in the fundamental frequency of the vocal cords: about 130 Hz for male voices and about 205 Hz for female voices.

1.3 Hearing protection without distorting the sound

It is therefore vital to protect our hearing as soon as the noise level is high, but it is also equally important to perceive sounds without truncating whole sections so that they can be identified.

1.4 The human ear

Our ear has the ability to naturally amplify the high frequencies. This is due to our external ear having a conical shape that amplifies loud noise from 10 to 15 dB on an average.

We see in Chart 1 that a sound of 1 KHz perceived at 20 dB (green curve) is not at the same level at all frequencies. It will be amplified around 3.2 KHz and will be less well perceived at low frequencies.

When the natural amplification of the ear is stopped, we lose the perception of some high frequencies that we usually hear.

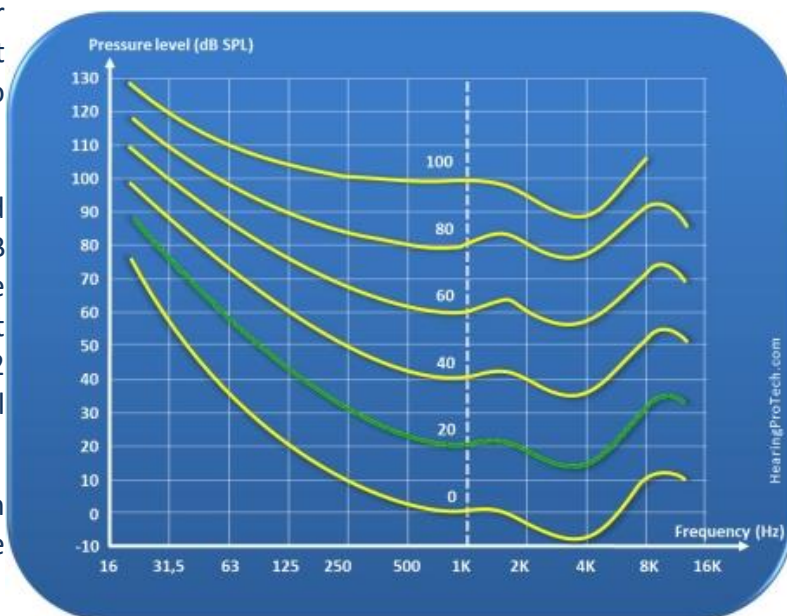


Chart 1: Equal-loudness contours (ISO 226). Measurements of sound pressure in decibels, based on the frequency that a person perceives as sound at the same level.

This is exactly what happens when we wear hearing protectors. An earplug placed in the ear canal or a helmet which covers the ear immediately stops the natural amplification of high frequencies. Everything becomes more "deaf" and more "low-pitched". Less problematic when two hours are spent working with a jackhammer or mowing the lawn, this distortion of our sound perception quickly becomes problematic when it involves listening to a concert, playing an instrument in a symphony, or simply communicating with colleagues at work.

As a consequence of this distorted sound, the hearing protector that is removed intermittently, or not worn, incurs a risk of hearing loss.

Many musicians with a significant hearing loss or tinnitus suffer due to excessive noise exposure: Neil Young, Barbra Streisand, Pete Townshend (The Who), John Entwistle (The Who), Brian Wilson (Beach Boys), Sting, Eric Clapton, The Edge (U2), Phil Collins, Ludwig Van Beethoven, Robert Schumann...

"If only due to the whistling and humming in my ears day and night, I would say that my life is an ordeal." Ludwig Van Beethoven

1.5 Hearing protection

It is imperative to protect ourselves from noise. Regulations exist to protect the employee for whom the employer is required to provide hearing protection from 80 dB (A) for exposure of 8 hours per day. The employer is still required to ensure that the employee is effectively protected from 85 dB (A) (DIRECTIVE ON "NOISE" 2003/10 / EC OF THE EUROPEAN PARLIAMENT, 2003).

If all hearing protectors must be CE certified, one must be particularly vigilant in case the protectors are used in the workplace. It is imperative for the selected protector to be certified by an organization such as CRITT (France), IFA (Germany), TNO (Netherlands), or INSPEC (Great Britain).

A protector can be perfectly certified in Germany and sold in France; it is important that in the European Community it must follow EN352-2.

To obtain this certification, the protector must meet criteria such as impact resistance, heat, minimal attenuation...

Frequencies in Hz	125	250	500	1000	2000	4000	8000
APV in dB *	5	8	10	12	12	12	12

Table 2: Requirements of the EN352-2 standard for minimum attenuation per frequency * APV: "Assumed Protection Value" average attenuation for each frequency for which the standard deviation is subtracted.

It is also important to check that the manufacturer of the hearing protector has obtained a certification in his name. This is the only way to ensure that the marketed protector is manufactured by the same process as that which has been certified.

Outside the world of work, few actions are implemented to prevent the risk of overexposure to noise.

The regulation imposes a limit on concert halls and private discos, but it is quite common for an outdoor concert to generate sound levels from 120 to 140 dB near the speakers.

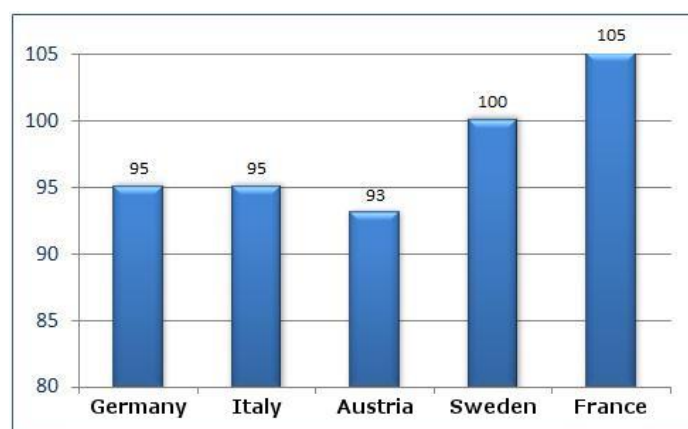


Chart 2: Regulatory limits not to be exceeded in concert halls and discos of different countries

With regard to music players, the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), estimated that between 50 and 100 million citizens of 27 countries of the European Union listen to music every day on music players, and identified between 2 and 10 million people among them as being at risk.

"People who use music players are at risk of permanent hearing loss if they set the volume too loud and use the device for more than an hour a day every week for at least 5 years," warns CSRSSEN.

In 2012, in Europe, digital music players are limited to 100 dB in theory, but it is not difficult to find an MP3 player whose sound level meets 120 dB. The United States has no imposed limit. Internet forums are full of advice to "go beyond" the limits of the iPhone, for example. Knowing that exposure to a sound level of 100 dB (A) for longer than five minutes is harmful to hearing, one can easily imagine the consequences of being exposed to 110 dB for several hours a day with an MP3 player.

1.6 Two large families of hearing protectors

1 - **Ear muffs** that cap the ear.

2 – **Earplugs** that fit into the ear and encompass three categories:

a - **standard earplugs requiring shaping** by the user, made of foam, must be shaped to reduce the diameter prior to insertion into the ear canal.

b - **preformed standard plugs** which are generally made of silicone or elastomer with vanes. Their insertion into the ear canal is done directly without needing shaping.

c - **customized earplugs** made from an impression of the future wearer's ear, are made of silicone or acrylate resin.

Each type of protector has its advantages: the cost for some (occasional use), efficiency and comfort for others. The vast majority of them have a "classic" attenuation, as opposed to protectors that have a "flat response" attenuation.

2 Uniform response hearing protection

As we discussed in Chapter 1.4, closing the ear using a protector suppresses its natural amplification of high frequencies, which directly generates a significant attenuation on the same frequencies. Since the attenuation is less at medium and low frequencies, the attenuation is not flat. A distortion in the perception exists and it may be relatively large. For the identification of this type of attenuation in this study, we will give it the name "classic" or "non-uniform" attenuation.

Some activities require the wearing of hearing protectors as well as a faithful reproduction of the sound environment.

To meet this need, Elmer Carlson at Knowles invented a uniform response filter in the 1970s. Today, known as "ER15", it is developed and marketed by Etymotic Research. ER filters (Etymotic Research) are currently marketed and used worldwide.

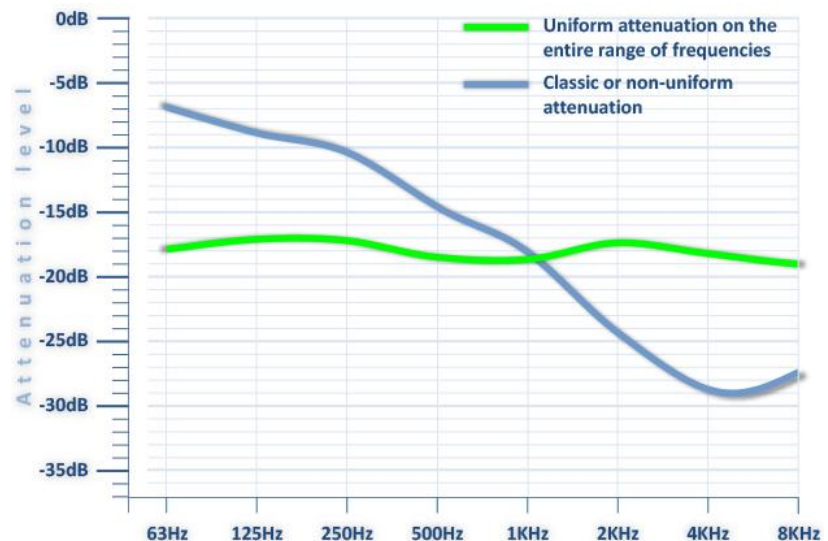


Chart 3: Attenuation curves of two protectors with both having the same overall level of attenuation (SNR). It is noted that in the case of a "classic" protector, represented by the blue curve, differences of up to 20 dB exist between low frequencies and high frequencies. A good uniform response protector has in theory very little variation on the attenuation of each frequency. It is this consistency that provides good sound reproduction without distortion.

2.1 The quality of the hearing protector

Two essential elements compose the protector:

- 1 - The casing (the hearing protector without the filter) made of silicone elastomer or acrylate resin. It must be of excellent quality. Customized protectors are included in this case. A little later into the comparison, we shall see a clear advantage.
- 2 - The filter that is the most important element of protection to get a flat attenuation over all frequency bands.

The filter of protectors with "classic" attenuation, where used, allows air passage. This acoustic leak, deliberately generated and controlled by a length/diameter equation of the bore in the filter, provides different intensities of overall attenuation.

The acoustic leak thus generated causes an immediate loss of attenuation at low frequencies, without penalizing the high frequencies, which further increases the attenuation differences between frequencies.

To obtain a uniform attenuation across all frequencies, it is necessary to generate no sound leakage, so that it allows correct attenuation at low frequencies. Too much attenuation at high frequencies, resulting from the closure of our ear canal (see Section 1.4) must be limited to reduce it to low frequencies. The filter is made of a membrane which seals and which

vibrates at high frequencies (2700 Hz), amplifying them to get a consistent set between low and high frequencies.

2.1.1 Manufacturing parameters that are fully met

Major manufacturing constraints for the previous generation filters

The diameter and length of the bore between the filter and the end of the protector (ear drum side) must be scrupulously matched. Thanks to this setting, the membrane vibrates or does not vibrate, to produce a re-amplification of high frequencies. It must in some cases be very large (this is the case for the ER filter), hence the difficulty of manufacture for persons with small and narrow ear canals. People with narrow ear canals (<5 mm) are many and it is not certain that this type of protector is not provided to them on the grounds that their ear canals are too small. We can thus assume that the attenuation of their protectors does not always match the values displayed by the suppliers.

The new generation filters

New filters reduce these constraints and adapt to a greater number of ear morphologies. This is the case of PRO filters by ACS and FT filters by Cotral.

Innovative manufacturing processes

New digital manufacturing processes (3D modeling, additive manufacturing) allow the manufacture of customized protectors ensuring full dimensional control of the manufactured product. These technologies contribute to their accuracy, unquestionable reliability, and a result in line with the values displayed by the manufacturer.

The generalization of these technologies, even if the entry is still new, will in a few years form the majority of market participants, producing hearing protectors with this level of reliability. This process uses acrylate resins. The protector is made of a hard material, while the vast majority are made of soft silicone. This does not seem to cause comfort problems, and gives the protector strength and a longer life.

2.1.2 A deep insertion hearing protector to prevent occlusion

Speaking or chewing produces movements in the fibro-cartilaginous part of our external ear. The sound is transmitted by this fibro-cartilaginous part inside the ear canal and naturally escapes to the outside of the ear (Figure 2, view 1).

Placing an earplug in the duct will trap the sound by returning it to the eardrum (Figure 2, view 2).

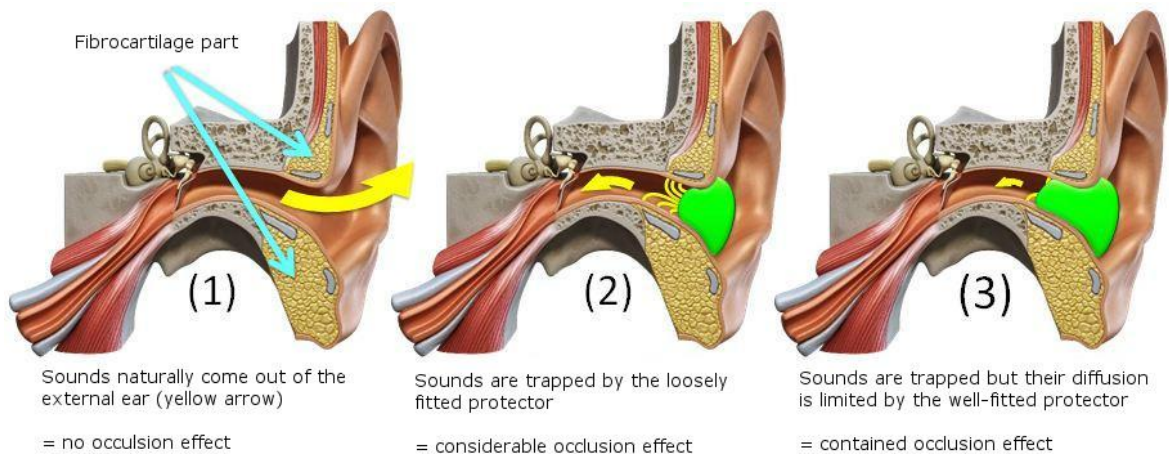


Figure 2: the occlusion effect is caused by the closing of the ear canal, the fibrocartilage portions (orange) transmit our own voice in the ear canal (view 1). The closing prevents the sound waves from going out and returns them to the eardrum (view 2) which has the effect of amplifying it. This resonance is unpleasant and difficult to bear. The solution is to wear a deep insertion fibrocartilage that covers parts, blocking their transmission to the ear canal (view 3).

These "deaf" sounds are amplified approximately 20 dB at low frequencies up to 500 Hz to decrease and become zero at 1700 Hz. This amplification is what the subject will hear "in addition" to his own voice. It is hard to get used to this troublesome resonance. The positioning of the protector in the ear canal plays a major role in the occlusion effect. The depth of insertion of the protector has a major influence. The shorter it is, the freer the fibro-cartilaginous part is to generate vibrations.

Conversely, a deep insertion prevents this disadvantage. Customized protectors are therefore preferred to avoid this (Berger, 1983).

Those who choose a uniform response protector to communicate (speak) or sing (band, choir) should be particularly vigilant on this point when choosing them.

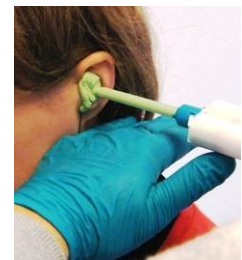


Figure 3: Impression required to make a customized protector

3 Evaluation of hearing protectors

3.1 Classification of hearing protectors according to the uniformity of the attenuation across all frequency bands

Tables 4 and 5 show the classification of protectors depending on their level of uniformity, which was evaluated according to the standard deviation method applied to eight frequencies of 63 Hz to 8 KHz.

The lower the standard deviations between the frequencies (close to 0) the better the uniformity, so the perception of the environment is also better.

Details on the various columns composing these tables:

1. **Models**: Product Name.
2. **Marketed by**: Name of the distributor may also be the manufacturer
3. **Manufactured by**: Name of the manufacturer
4. **CE standard**: The protectors were identified in 3 cases:
 - 1 - The protector was analyzed by a certifying body. It meets the specifications of the CE EN352-2 and obtained the "CE" mark; it is marked as "CE" in the comparative table.
 - 2 - There is no information available on possible "CE" certification; it is not possible to know the method used to measure the attenuation of the protector. In the case where the attenuation levels meet the minimum required by the standard, the protector is rated "?".
 - 3 - The protector does not meet the minimum attenuation required by EN352-2, it is marked "~~CE~~". It is emphasized that this protector may well be used in environments where the sound level is less than 85dB (A) without risk to the wearer.
5. **Rates**: Rates are indicative for a pair of protectors. Some products can be marketed by various companies, and their rates may vary. Rates of companies located abroad were converted into euro with the following exchange rates:
Euro/dollar: €1 = \$1.37
Euro/Pound Sterling: €1 = £0.87
All rates are inclusive of all taxes.
6. **Frequencies of 63 Hz to 8000 Hz**: Attenuation is measured for each frequency in decibels. It is these values that will both determine the uniformity of the attenuation and its overall attenuation level (SNR). These values were

measured in the laboratory during the certification, either measured by the manufacturer. Neither the method nor the conditions are explained.

7. **SNR value:** Overall attenuation index (Single Number Rating), calculated using the EN4869-2 standard, is a weighted average of attenuation at all measured frequencies. The choice of the attenuation level (SNR) must be made taking into account the intensity of sound levels in which the protector is used.
8. **HML:** The HML values, calculated according to the EN4869-2 norm, give the average attenuation at high (High), medium (Medium) and low (Low) frequencies.
9. The standard deviation: represented by Sigma "σ", is calculated according to the following methods: $\sqrt{\frac{\sum(x-\bar{x})^2}{n}}$ wherein "x" is the average of the sample and "n" the sample size.

The column represented by the letter "σ" represents the difference between different attenuations measured on frequencies between 63 Hz and 8 KHz (some protectors do not display the attenuation at the frequency 63 Hz, which is optional). The weaker the "σ" (near 0), the more uniform the attenuation is said to be, and thus the better the protector is in its response.

10. **Score:** The score gives a quick idea of the quality of the attenuation of the protector. The scores were imparted according to the following rule:
11. **Max. difference:** Represents the difference between the highest and lowest attenuation measured on two frequencies. The differences range from 3.50 to more than 30 dB!

σ	Score	Estimate
[0.50 ; 0.99]	*****	Excellent
[1.00 ; 1.49]	****	Very good
[1.50 ; 1.99]	***	Good
[2.00 ; 2.99]	**	Fair
[3.00 ; 3.99]	*	Average
[4.00 ; 4.99]	■	Poor
[5.00 ; 5.99]	■■	Bad
> 6.00	■■■	Very bad

Table A3: criteria determining the score of Tables A1 and A2

	Product: Standard preformed protectors						Average loss in Hz								Average				Evaluation		
	Models		Marketed by	Manufactured by	CE	Prices €	63	125	250	500	1000	2000	4000	8000	SNR	H	M	L	σ	Score	MAX difference
1	ER20		Etymotic Research	Etymotic Research	?	20.00 €		10.7	13	14.5	15.2	18	16.3	18.7	18	17	16	13	2.59	**	8.00
2	Push-Ins		3M	3M	?	0.61 €	29.8	31.3	32.2	35.7	34.9	36.8	38.1	37.4	38	37	36	34	2.87	**	8.30
3	MultiMax		Howard Leight	Howard Leight	?	0.11 €	27.8	30.1	31.1	33	31.1	32	37.3	36.8	35	33	32	32	3.04	*	9.50
4	ALVIS Mk2		Alvis Audio	Alvis Audio	?	24.90 €	25.6	28	27.1	27.5	28.3	28.9	28.9	37.5	31	29	29	29	3.38	*	11.90
5	Fidelity ER20		Acoufun	Etymotic Research	?	29.90 €		14.5	15.3	16.9	18.9	22.5	19.8	24.6	21	21	19	16	3.43	*	10.10
7	Pianissimo S20		Protac	Protac/Etymotic	?	20.00 €		10.7	12.5	14.4	15.9	19.1	17	22	18	18	16	13	3.58	*	11.30
8	Max		Howard Leight	Howard Leight	?	0.07 €	31.6	32.6	33.1	35.1	34.7	33.9	43.8	37.6	37	36	35	34	3.64	*	12.20
9	Max Lite		Howard Leight	Howard Leight	?	0.07 €		29.2	29.6	32.4	31.3	30.1	38.1	38.6	34	32	32	31	3.68	*	9.40
10	X-Fit		Uvex	Uvex	?	0.40 €	31.1	32.1	34	35.3	33.4	33.5	42	40.5	37	36	34	34	3.68	*	10.90
11	Ultratech		3M	3M	?	22.99 €	11	12.3	14.5	16.4	18.3	23.3	18.3	22.3	21	18	18	16	4.12	■	12.30
12	Ultrafit X		3M	3M	?	1.70 €	28.4	29	27.5	30.1	32.5	32.7	38.4	39.2	35	35	32	30	4.17	■	11.70
13	whisper		Uvex	Uvex	?	1.99 €	20.5	20.8	20.2	21	23.7	27.8	26.1	32.8	27	27	24	22	4.22	■	12.60
14	MusicSafe Pro Silver		Audilo	Alpine	?	24.00 €		14.8	15.8	15.7	18.7	26.6	24.4	18.9	21	23	19	15	4.23	■	11.80
15	PartyPlug		Auditive.fr	Alpine	?	13.00 €		14.8	15	15.7	18.7	26.6	24.4	18.9	21	23	19	15	4.33	■	11.80
16	Earpad Universal		Earsonic	Earsonic	?	24.00 €	5.3	6.9	8.1	10.1	12.1	18.1	17.8	13.4	15	16	12	10	4.48	■	12.80
17	MusicSafe Pro Gold		Audilo	Alpine	?	24.00 €		18.8	15.6	16	18.5	27.7	28.9	22	22	25	19	16	4.98	■	13.30
18	MusicSafe Pro White		Audilo	Alpine	?	24.00 €		10.2	11.2	14.3	17.9	24	23.4	18	20	22	17	13	5.06	■■■	13.80
19	QuietEar		Ear Plug Superstore	HearTech	CE	5.95 €		5.1	6.3	9.9	11.6	17	27.2	28.9	16	18	12	9	8.92	■■■■	23.80

Table 3: Classification of standard preformed hearing protectors according to the uniformity of the attenuation across all frequency bands

	Products: Customized protectors					Attenuation								Average				Evaluation		
	Models	Marketed by	Manufactured by	CE	Rates €	63	125	250	500	1000	2000	4000	8000	SNR	H	M	L	σ	Score	MAX difference
1	PRO17	ACS	ACS	CE	€160.14		17.9	17.9	15.9	15.8	14.7	17.4	16.5	17	16	16	16	1.12	*****	3.20
2	Original White FT19	Cotral	Cotral	CE	€155.00	19.1	19.6	17.3	18.7	18.6	16	17.9	19.3	19	17	18	18	1.12	*****	3.60
3	ER15	Elacin	Elacin / Etymotic	CE	€151.00		13.7	14.6	15.2	13.7	14.7	13	16.9	16	14	14	14	1.18	*****	3.90
4	Clearsound RC19	Elacin	Elacin	CE	€115.00		19	19.2	19.7	20	19.4	16.4	22.3	20	18	19	19	1.61	***	5.90
5	ER15	Acs	ACS	CE	€189.52		15.7	14.7	12.7	13	12.5	12.3	16.8	15	13	13	13	1.65	***	4.50
6	ER25	Acs	ACS	CE	€189.52		22.3	22	20	20	20	20	25	22	20	20	18	1.77	***	5.00
7	Clearsound RC18	Elacin	Elacin	CE	€115.00		14.4	16	17.8	18.3	19.1	18.6	14	19	17	18	17	1.93	***	5.10
8	PRO15	Acs	ACS	CE	€160.14		11.1	11.6	11.9	12.2	12.7	15.3	17.2	15	14	13	12	2.08	**	6.10
9	ER25	Elacin	Elacin / Etymotic	CE	€1535.00		17.9	19.5	22.5	20.7	21.1	25.2	20.9	23	22	21	21	2.13	**	7.30
10	Original White FT24	Cotral	Cotral	CE	€155.00	18.3	19.4	19.6	22.5	23.8	22	20.1	26.2	24	22	22	21	2.47	**	7.90
11	ER9	Acs	Acs	CE	€189.52		12	11.6	9.2	9.2	6.7	8	14.5	10	8	9	9	2.47	**	7.80
12	Safe Sound RC19	Elacin	Elacin	CE	€115.00		19.4	20.9	21.4	20.8	15.6	23.5	23.8	21	18	19	20	2.55	**	8.20
13	Solocom	Elacin	Elacin	CE	€115.00		20.5	19.4	21.1	20.2	26.7	25.6	23.1	24	25	22	21	2.63	**	7.30
14	FlexComfort ML1	Elacin	Elacin	CE	€115.00		26.1	24.2	23.5	25.4	28.5	32.6	25.8	28	28	26	25	2.86	**	9.10
15	ER9	Elacin	Elacin / Etymotic	CE	€150.00		10.4	9.4	5.8	6.8	10.3	9.2	15.5	10	10	8	7	2.89	**	9.70
16	Clearsound RC17	Elacin	Elacin	CE	€115.00		9.5	12	16.7	16.7	20.6	16.4	14.3	18	17	17	14	3.35	*	11.10
17	Safe Sound RC18	Elacin	Elacin	CE	€115.00		16.3	18.3	17.4	18	15.8	22.1	26.4	20	18	18	18	3.50	*	10.60
18	PRO20	Acs	Acs	CE	€160.14		13	14	17	17	21	20.5	24.5	20	21	18	17	3.79	*	11.50
19	Original White FT15	Cotral	Cotral	CE	€155.00	9.2	8.5	9.5	10.3	12.1	14.9	17.3	20	15	16	12	11	3.96	*	11.50
20	FlexComfort MM02	Elacin	Elacin	CE	€115.00		18.9	21.8	20.8	24.6	26.8	31.8	25.9	27	27	24	22	4.01	■	12.90
21	Phonor Select	Infield Safety	Infield Safety	CE	€196.74		21.2	19.8	21.7	22.9	29.3	26.5	31.4	27	28	24	22	4.10	■	11.60
22	Clearsound RC15	Elacin	Elacin	CE	€115.00		7.3	9.6	13.7	14.4	19.7	19.6	12.3	17	17	15	12	4.33	■	12.40
23	High flex-fit LS27	Uvex	Uvex	CE		16	18.9	21.3	23.6	23.6	27.2	30.9	25.1	27	27	25	23	4.37	■	14.90
24	LD 24	Jrenum	Jrenum	CE		25.2	27.3	25.2	28.6	29	33.7	37.6	35.2	33	34	30	28	4.39	■	12.40
25	PRO27	Acs	Acs	CE	€160.14		21.8	21.9	22.9	22.5	24.8	31.9	33.7	27	27	24	23	4.64	■	11.90
26	Moderato25	Auditech	Auditech	CE	€110.00	15.2	18.9	18.9	21.5	21.1	29	27.1	30.1	26	27	23	21	5.04	■ ■	14.90
27	Tuttissimo RC13	Protac	Protac / Elcea	CE			4.1	6.7	10.8	12.8	18.1	19.3	12.8	15	16	13	9	5.12	■ ■	15.20
28	Serenity XC92WH	Phonak	Phonak	CE			18.5	20.4	22.2	30.2	33.6	31.6	27.2	29	31	27	22	5.48	■ ■	15.10
29	Muzik EP2	Surdifuse	Surdifuse	CE	€150.00	24	27	26	30	32	34	41	40	30	33	28	19	5.89	■ ■	17.00
30	Moderato15	Auditech	Auditech	CE	€110.00	6.5	7.1	10.3	14.6	17.5	23.2	20.5	23.6	20	22	17	12	6.45	■ ■ ■	17.10

Table 4: Classification of customized earplugs according to the uniformity of the attenuation across all frequency bands

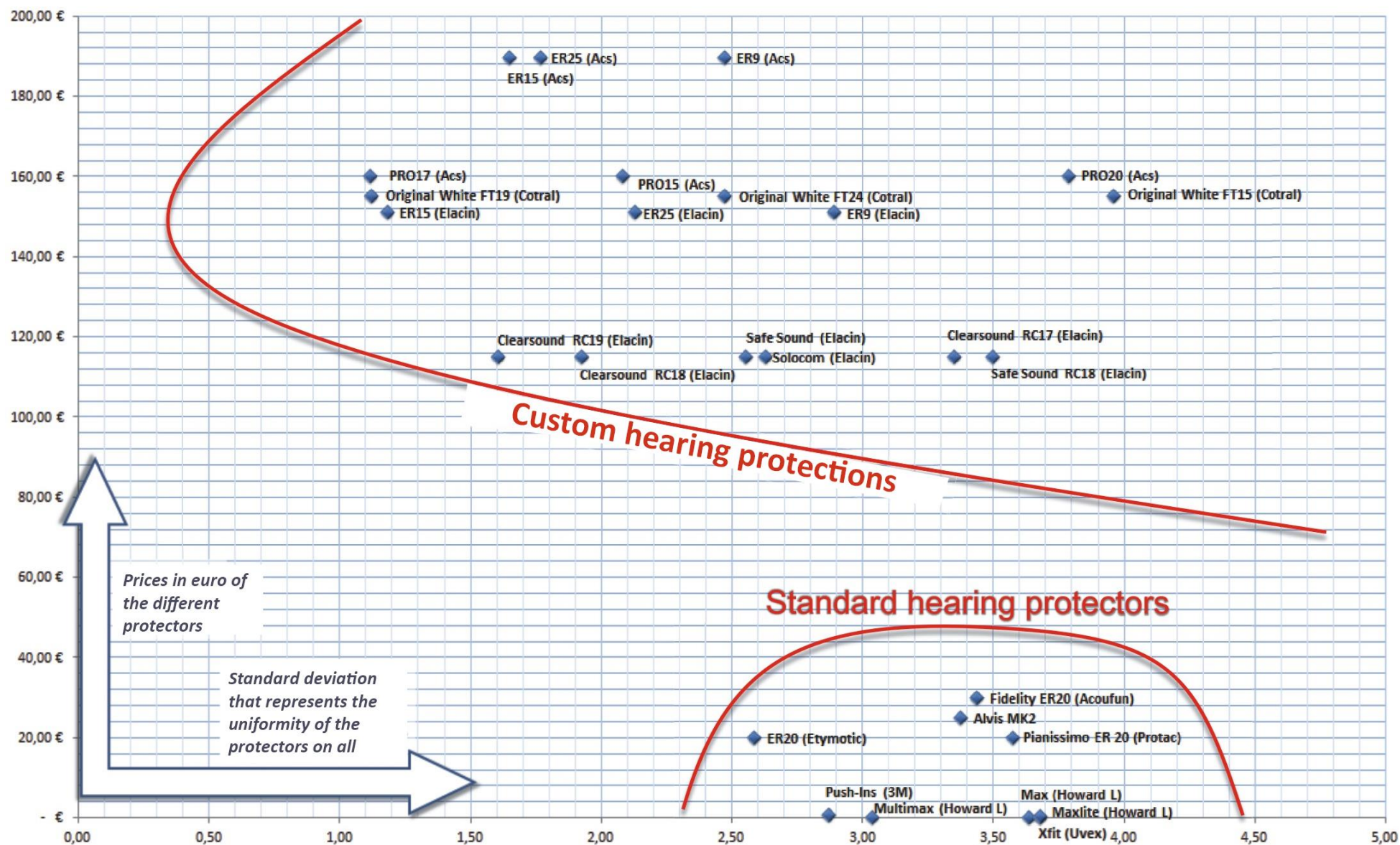


Chart 4: Positioning of hearing protectors by their standard (σ) and their selling price. For clarity, only the protectors with a standard deviation of less than 6 are represented

3.2 Analysis of results

Three models in a confined space

Three protectors showed very similar results.

The PRO17 model by ACS Exaequo tied with the Original White FT19 by Cotral, closely followed by ER15 by Elacin with the respective standard deviations of 1.12 and 1.18.

No protector 5 stars

No protector shows a completely uniform attenuation (standard deviation < 1), enabling it to get 5 stars.

The customized protectors are more efficient than standard models

The twelve best protectors are customized models. This technology, even though it costs more, provides more consistent results compared to standard models. We also observe that the standard protectors are usually "closed", and have no filter and obtain good results in consistency with this seal. They are characterized by a very low cost at the expense of very high attenuation, rarely suitable for listening to music or speech. Only the ER20 model, developed by Etymotic and marketed under the names of ER20 or S20, offers a standard earplug suitable for listening without distortion. It is difficult to discuss "listening" with Push-ins by 3M offering an extremely high attenuation (38 dB SNR).

Eighteen protectors have very disappointing results

Eighteen products are identified as "bad" or "very bad" and do not deserve the name "flat response".

Do not forget to assess what would be the use of the protector

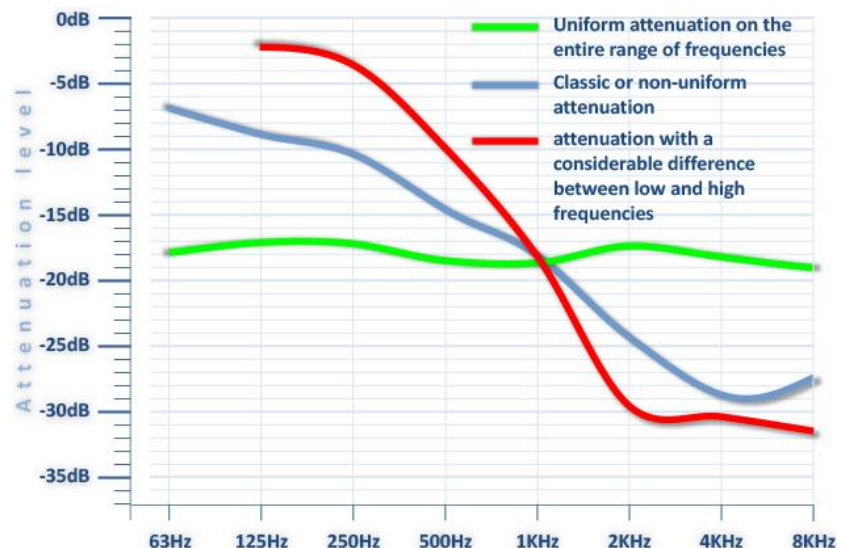
The best standard protector is better in terms of standard deviations than many customized protectors. For occasional use (concert, noisy environment), without doubt, the ideal model is the preformed earplug ER20 by Etymotic. It offers the best value for price.

For frequent or continuous use, investing in a more comfortable customized protector allows for continuous wear and ensures safe hearing protection. Customized models also ensure a more uniform attenuation, and are more reliable.

Allegations of uniformity or natural hearing is somewhat misleading

If thirty protectors obtain a satisfactory result, many sellers boast about their natural response, their effectiveness for musicians, and their capacity to foster communication, without providing any uniform or natural response.

The visible red curve on Chart 5 shows the protector with the highest standard deviation. It is easy to see the difference between a protector whose uniform response attenuation is less than a standard deviation of 2 (green curve) and a protector with a non-uniform attenuation whose standard deviation is greater than 10 (red curve).



This highlights how important it is, before selecting a hearing protector with a uniform response to attenuation, to not listen to the seller's claims, but to monitor the attenuation by frequency.

In case the protector is designed for use in business, ensure that the selected model meets the minimum requirements of the standard EN352- 2 (Table 2) enabling it to obtain the CE mark. The protectors having the CE certificate are specified in column CE in Tables 3 and 4.

3.3 What is the level of attenuation that must be chosen?

The SNR determines the "power" of the attenuation of the protector.

The first question that should guide your choice is: "Am I sufficiently protected?" The notion of uniformity will only come in later.

Whether the protector plays its role well or not, it is important to know the level of noise you are exposed to. Once this level is defined, simply deduct 80 (decibel level under which the hearing is not at risk). The result will be the degree of attenuation required, it is then sufficient to compare it with the level of SNR of different protectors.

Example 1

You work in noisy environments and are exposed to 93 dB (A) for a period of 8 hours/day. 93 dB (A) exposure level – 80 dB (A) safe level = 13 dB
The protector must offer a minimum SNR of 13 dB

Example 2

You regularly attend concerts, you make sure not to sit near the speakers. Despite that, the noise level is very high, about 110 dB, and the duration of a concert is usually 2 hours (without the first part). This corresponds to an exposure of 103 dB (A) for the reference time (8 hours)
103 dB (A) exposure level – 80 dB (A) safe level = 23 dB

3.4 Focus on three hearing protectors

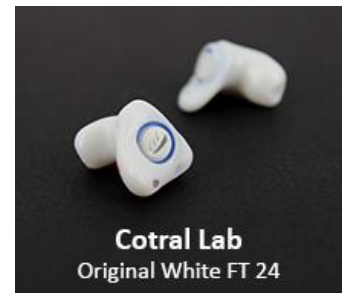
Let us study in detail three protectors with uniform response.

1. One of the two best in terms of consistency, Original White FT19 by Cotral
2. The most commonly used, the customized ER15 by Etymotic, which is in this case manufactured by Elacin
3. The best standard protector with uniform attenuation, the ER20 by Etymotic

1. The Original White FT19 model by Cotral Laboratory.

Made of acrylic resin (Crylit), this custom protector is white.

Made with 3D digital technology, according to its manufacturer, it offers an accuracy of about 50 microns, which, combined with a new generation of uniform response filter, allows it to reach (fairly) the top of the level.



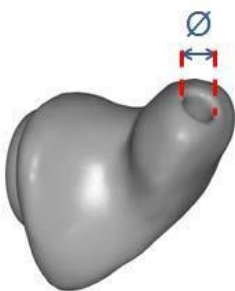
Very simple to set up, it offers good comfort. It is so far marketed only to companies and sound experts (musicians, sound engineers, DJs...)

Its price is around €155. This product was certified in February 2011 in CRITT (France) by "Cotral" according to EN352-2.

2. The customized ER15 model, manufactured by Elacin.

Made of silicone, this protector is translucent pink; manufactured manually, it is comfortable, and the implementation is easy.

The ER15 filter, marketed by Etymotic Research, has proven itself over many years.



A first generation filter, it imposes constraints that may restrict equipment for people with narrow ear canals. These constraints are described by Mead Killion (Killion et al, 1988). The bore which passes through the protector to allow sound to be diffused to the middle ear must have a diameter of at least 3.5 mm to 4 mm if the ear canal is round, and 3 to 5 mm if it is more of an oval shape.

Its price is around €151. The product has been certified as BIA (Germany) in 1993 by Elacin according to EN352-2.

ER15 and ER25 filters by Etymotic (US) equip many protectors marketed in Europe by: ACS; ALS; Audilo; Dreve; Elacin; Egger; Elcea; Exinor; Protac (Pianissimo); Infield; Weston (Musicians style 49); independent hearing care professionals ...

To date, only the companies Elacin (NL) and ACS (UK), have achieved a certification of these ER15 and ER25 filters on the protectors they manufacture.

3. The ER20 preformed earplug model, manufactured by Etymotic

Manufactured in series, made of a flexible material (not defined) for the portion inserted into the ear canal, a rigid rod in which the filter is located, serves as a grip for implementation. It comes in two sizes to suit the majority of ear canals.

Placing it in the ear takes a little practice, it is often necessary to pull the ear up for proper insertion. Comfort is okay for a short use.



The price varies from 10 to 20 € according to the distributor. The product was certified in CIOP-PIB (Poland) by Etymotic (?) according to EN352-2.

4 Conclusion

The first objective before determining whether a protector provides a uniform response across all frequencies is to ensure that it protects hearing effectively.

The critical level at which risks exist for the hearing is 80 decibels for a period of 8 hours (DIRECTIVE on "NOISE" 2003/10 / EC OF THE EUROPEAN PARLIAMENT, 2003). It is important to know that as the noise intensity increases, the exposure time should be limited. Exposure to 95 decibels should not last more than fifteen minutes without protection.

Some activities require hearing protection as well as a good perception of the environment. This is the case for people who need to communicate in a noisy environment. An adjuster who develops ear devices, a musician in a symphony orchestra are examples.

The human ear has the particularity to naturally amplify the treble. The fact of sealing the ear canal cancels this amplification. Result: ordinary hearing protectors will offer very significant attenuation at high frequencies, causing an imbalance between the bass and treble frequencies. They are not suitable for people requiring reliable sound reproduction.

Two types of uniform response hearing protectors are available, standard systems and custom-made systems. If the standard protector benefits from a perfect manufacture, it is its implementation that can sometimes be problematic. Maximum care should be given to the manufacture of customized protectors. In principle, it fits perfectly in the ear for which it was designed.

The value used to establish a comparison between different protectors is the standard deviation calculated on each attenuation value, frequency to frequency, 63 Hz to 8 KHz. Results vary by 1 for the most uniform protectors to 13 for those that are not uniform. We find that three custom models compete for the first place and

one model dominates the others in the standard category, whose uniformity does not equal the customized protectors on the price, which is seven times more, but offers excellent value for the money.

5 Bibliography

Berger, H. (1983). Occlusion Effect on the Measurement of Real-Ear Attenuation at Threshold.

DIRECTIVE on "NOISE" 2003/10 / EC OF THE EUROPEAN PARLIAMENT, (2003, February 6), *concerns the minimum safety and health requirements for workers' exposure to noise*. Official Journal of the European Union.

Killion et al. (1988). Earplug with 15dB attenuation.

Appendix 6: Contact details of manufacturers and distributors

<i>Last name</i>	<i>Address</i>	<i>Country</i>	<i>Phone</i>	<i>Internet</i>
3M	95006 Cergy-Pontoise Cedex	France	0 810 331 300	http://solutions.3mfrance.fr
Acoufun	75012 Paris	France		http://www.acoufun.com
ACS	Oxfordshire, OX16 1TG	United Kingdom	01295 266665	http://www.acscustom.com/uk/
Alpine	Hulbert, OK 74441	United States of America	(918) 512-4188	http://alpineearplugs.com
Audilo	75009 Paris	France	01 40 82 90 78	http://www.audilo.com/
Auditech	76161 Danétal	France	02 35 60 57 24	http://www.audipack.fr/
Auditive.fr	75015 Paris	France	09 81 11 62 61	http://www.auditive.fr/
Cotral	14110 Condé sur Noireau	France	02 31 69 36 36	http://www.cotral.com/
Ear Plug Superstore	Hulbert, OK 74441	United States of America	918 478 5500	http://www.earplugstore.com
EarSonics	34830 Clapiers	France	04 67 59 36 20	http://www.earsonics.com/
Elacin	5100 AE Dongen	Netherlands	31 162 372526	http://www.elacin.com
Etymotic	Elk Grove Village, IL 60007	United States of America		http://www.etymotic.com/
HearTech	RA'ANANA 43101	Israel	972 9 7445636	http://www.heartech.co.il
Howard Leight	7828 Waterville Road	United States of America	800/430-5490	https://www.howardleight.com
Infield	42719 Solingen	Germany	0212-23234-0	http://www.infield-safety.de
Jrenum	4001 Basel	Switzerland	61 269 82 22	http://www.jrenum.com
Phonak	8712 Stäfa	Switzerland	58 928 01 01	http://www.phonak.com/ch
Protac	30111 Congenies	France	04 66 80 22 89	http://www.interson-protac.com/
Surdifuse	75462 Paris	France	01 47 70 97 11	http://www.surdifuse.com/
Uvex	90766 Fürth	Germany	0911 / 97 74-0	http://www.uvex.de

Table A4: List of different distributors and manufacturers mentioned